

FACTORS AFFECTING THE CARBON MONOXIDE DELIVERY IN CIGARETTE SMOKE

INTRODUCTION

Carbon monoxide is produced during the combustion and the pyrolysis of tobacco in the burning cone of the cigarette. There are many factors which influence the carbon monoxide yield in cigarette smoke : the combustion and pyrolysis conditions, the diffusion of gases in both directions through the cigarette paper, filtration conditions, smoke dilution with air, tobacco weight and puff number. Consequently, a number of means have been tried to lower the carbon monoxide yield of cigarettes and research in this direction is still ongoing.

Certain additives to tobacco change the combustion and pyrolysis characteristics in such a way that carbon monoxide is formed in lesser amounts. Work in this area is continuing, but so far the reduced carbon monoxide production was linked to other undesirable side-effects such as increased yield of polycyclic aromatic hydrocarbons and no practical solution was found hitherto.

The diffusion of gases through the cigarette paper in both directions is essential to maintain the free burning rate of the cigarette and plays an important rôle in reducing the carbon monoxide yield of mainstream smoke. In addition, cigarette paper has been developed with higher porosity or with special perforation allowing for an increased air-flow through the cigarette paper thereby introducing a smoke dilution effect.

2501015104

Experiments were unsuccessful when conducted in order to find adsorbents which selectively filter carbon monoxide. One of the problems is that carbon monoxide is isosteric to the nitrogen molecule and of similar molecular size so that the small amounts of carbon monoxide present in comparison to the large amounts of nitrogen, are virtually impossible to remove by selective filtration.

Catalytic filters, which would oxidise carbon monoxide to carbon dioxide, are excluded on thermodynamic grounds because of the exothermic character of the reaction.

So there are at present two practical possibilities to bring down the carbon monoxide yield of a cigarette :

- to reduce the amount of tobacco available for combustion and pyrolysis during puffs

and

- to dilute the smoke with air.

Both possibilities are being commercially applied at the present time.

There are obviously limitations to how much one can reduce the amount of tobacco available for combustion because the consumer expects a cigarette to be of a certain size and visibly filled with tobacco. He/she also expects to be able to draw a minimum number of puffs.

The dilution of the mainstream smoke by air through permeable filter wraps in addition to the previously mentioned dilution by air through the cigarette paper, has proved to be a practical way of reducing the carbon monoxide yield in cigarette smoke. However, it has to be borne in mind that the yield reductions achieved in this way are by no means proportional to the degree of dilution.

In order to explain how these two means of reducing the carbon monoxide yield interact, a very simplified model cigarette is described. It represents, perhaps, an over-simplification, but this does not invalidate the considerations which are developed in the following chapter.

2501015105

The simplifications or assumptions are as follows :

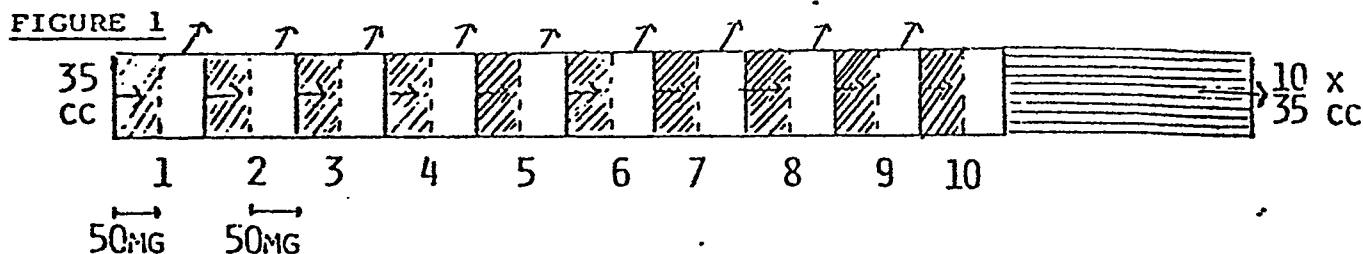
- Instead of the increase of smoke concentration with the rising puff number, a constant "average puff" is assumed from the beginning to the end.

- The free burning rate is assumed to be entirely proportional to the tobacco weight.
- No air dilution or carbon monoxide diffusion through the cigarette paper is assumed in order to simplify the quantitative considerations (in reality this cigarette would not burn).
- The tobacco weight is rounded up to 1 g per cigarette (reality nearer 850 mg).
- The tobacco burned during the puff and during the smouldering in the puff interval is assumed to be equal (in reality there is less tobacco consumed during the puff than during the puff interval).

THE MODEL CIGARETTE

EXAMPLE 1 : THE NORMAL STRENGTH CIGARETTE

- 1 g tobacco burned in 10 standard puffs.
- 1 puffing cycle lasts for 1 minute (2-second puff, 58-second interval).
- Half of the tobacco (500 mg) is used during the puff, half is consumed in the puff intervals.
- Total condensate yield : 20 mg/cig.
- Condensate yield per puff : 2 mg.
- Total CO yield : 20 mg/cig.
- CO yield per puff : 2 mg.
- Puff 35 ml of smoke, burning 50 mg of tobacco.
- Filter : standard filter efficiency.



EXAMPLE 2 : THE HALF-STRENGTH CIGARETTE (APPROACH VIA
DOUBLED FILTER EFFICIENCY)

All values and Figure 1 remain valid except that the smoke yields
are as follows :

- Total condensate yield 10 mg/cig.
- Condensate yield per puff 1 mg.
- Total CO yield 20 mg.
- CO yield per puff 2 mg.

Remark : undesirable condensate (nicotine) to CO ratio.

2501015107

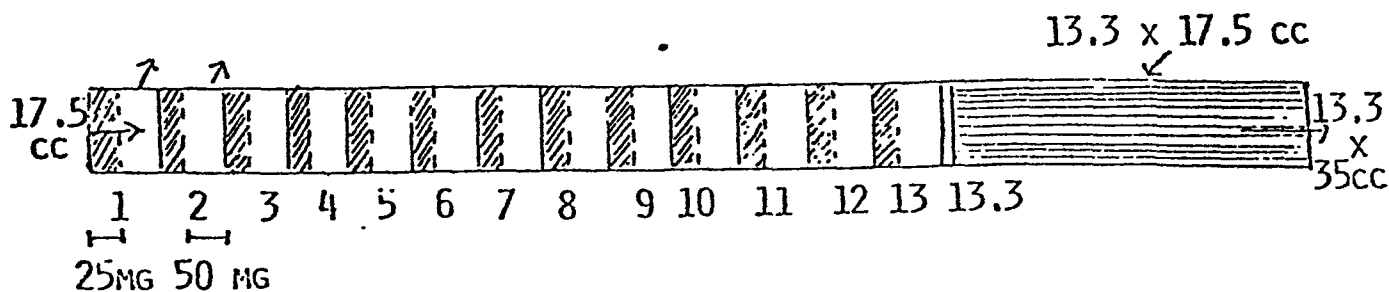
EXAMPLE 3 : THE HALF-STRENGTH CIGARETTE (APPROACH VIA
50% FILTER DILUTION)

- Puff volume at the filter end : 35 ml.
- Puff volume at the burning cone : 17.5 ml.
- Tobacco burned during puff : $\frac{50 \text{ mg}}{2} = 25 \text{ mg}$.
- Tobacco consumed during puff interval : 50 mg.
- Tobacco burned during one puffing cycle : 25 mg + 50 mg = 75 mg.
- Puff count = $\frac{1000 \text{ mg}}{75 \text{ mg}} = 13.3$
- Condensate yield per puff : 1 mg.
- CO yield per puff : 1 mg.
- Total condensate yield : 13.3 mg/cig.
- Total CO yield : 13.3 mg/cig.

Remark :

Whilst the 50% dilution of the smoke by air in the filter reduces the smoke yield per puff by half, the increase in puff count partially compensates the reduction in the overall yield.

FIGURE 2



2501015108

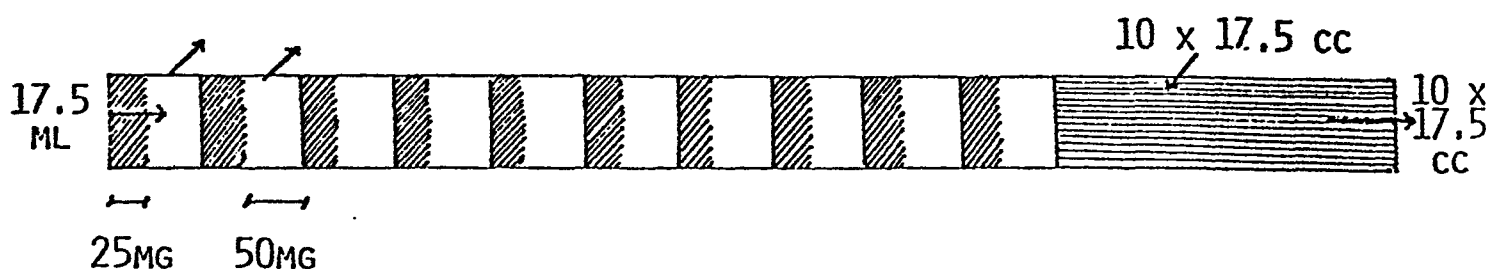
EXAMPLE 4 : THE HALF-STRENGTH CIGARETTE (APPROACH VIA
COMBINATION OF FILTER DILUTION AND REDUCED
TOBACCO WEIGHT)

- Tobacco weight: 750 mg (instead of 1 g).
- Filter dilution : 50 %.
- Puff volume at the burning cone : 17.5 ml.
- Tobacco burned during puff : 25 mg.
- Tobacco burned during puff interval : 50 mg.
- Tobacco burned during 1 minute cycle : 75 mg.

$$\text{Puff count} = \frac{750 \text{ mg}}{75 \text{ mg}} = 10.$$

- Condensate yield per puff : 1 mg.
- CO yield per puff : 1 mg.
- Total condensate yield : 10 mg/cig.
- Total CO yield : 10 mg/cig.

FIGURE 3



2501015109

CONCLUSIONS AND DISCUSSION

In the absence of satisfactory methods for the selective removal of carbon monoxide by the use of adsorbents in the filter or oxidation catalysts in the filter or additives to the tobacco, the approaches available at present for the reduction of the yield of carbon monoxide in cigarette smoke are :

- a reduction of the number of puffs per cigarette (e.g. by the use of reduced tobacco weight and/or cigarette papers of increased porosity with appropriate burn accelerators)
- dilution of the cigarette smoke by air through the use of highly porous or perforated cigarette papers and/or permeable filters.

These methods are not selective for carbon monoxide and any reduction in CO is accompanied by a reduction in the total smoke yield. Whilst carbon monoxide levels can be minimised by a balance of the techniques available, the use of these techniques is limited and if taken to extremes produces serious loss of product acceptability.

2501015110

As far as the model cigarette is concerned, the dilution of smoke through the filter rather than through the cigarette paper had been chosen for the sake of simplicity in order to avoid having to discuss a nonlinear situation. In reality, changes to the cigarette papers have played an important part in the steps the Industry has taken to reduce the carbon monoxide yields of cigarettes during the past few years. In fact, when a paper of increased inherent porosity is used, the prime effect is dilution of the smoke and reduction in both the particulate phase (tar) and the gas phase of each puff. However, the reduction in nicotine is less than the reduction in tar and the nicotine to tar ratio is therefore increased. The reduction in carbon monoxide yield is greater than in the reduction in tar yield, since smoke dilution is augmented by an enhanced diffusional loss across the cigarette paper of carbon monoxide and more complete oxidation

of the gases in the burning cone of the cigarette. Both condensate and vapour phase of the smoke are reduced and the balance between these phases is maintained.

The increase in paper porosity increases the cigarette free burning rate so that the puff count remains the same. However, the effect on the smoke is greatest in the early puffs and dilution and the other effects mentioned diminish as the cigarette is smoked at later puffs. Therefore, the use of highly porous paper introduces an imbalance between early and late puffs. The onset of this imbalance limits the level of ventilation which can be achieved through modification of the cigarette paper alone and in order to obtain large reductions in carbon monoxide yields it is necessary to make use of smoke dilution through permeable filter tips.

When filter tip ventilation is used to achieve major changes to smoke yield, choice of cigarette paper porosity and burn additive is still important in the control of the burning rate and puff count.

Mechanically or electrostatically perforated cigarette papers may be used instead of highly porous papers to reduce smoke yields. The effects of paper perforation on each puff are broadly the same as those produced when the inherent porosity of the paper is increased. However, perforation of the paper has no significant effect on the cigarette free burning rate so that the use of perforated paper leads to an increase in the puff count. A high level of perforation of the paper does, therefore, tend to produce a low taste impact in the early puffs.

In order to put the model cigarette into perspective with regard to reality, the assumptions are being discussed in the following :

2501015111

- Assumption "constant average puff" :

Differences in smoke yield between early and later puffs may need to be taken into account when considering the cigarette acceptability. Taste impact depends not only on maintaining acceptable average puff strength, it is also important that the early puff strengths do not fall below acceptable levels. This aspect has to be considered particularly when highly porous or perforated cigarette papers are used.

- Assumption "free burning rate proportional to tobacco weight" :

In order to make calculations easier, it is assumed in the model that a constant weight of tobacco is consumed during each puff interval. This is only true to a first approximation but other factors besides tobacco packing density play an important part in the control of the cigarette free burning rate, e.g. in the chemical composition of the tobacco (in particular the contents of inorganic and organic acid salts) and the quality of the cigarette paper (porosity and nature and quantity of burn additives).

- Assumption " no air permeability or CO diffusion through the cigarette paper" :

For the sake of simplicity, the effects of the cigarette paper are purposely not taken into consideration. This is to avoid having to discuss hyperbolic functions. The cigarette paper does, however, influence smoke yield and acceptability because of its effect on cigarette free burning rate and the dilution of smoke with air. Air permeability is necessary to keep a cigarette alight.

In the following, the various approaches to obtain the "Half-Strength Cigarette" are discussed.

2501015112

- Increased filter efficiency :

Whilst research has been undertaken with the aim of finding materials which might be incorporated in the filter to adsorb CO or to oxidise CO to CO₂, no commercially viable system has emerged. Systems which have been considered produce adverse side-effects on smoke composition, are easily poisoned by other smoke components or lack adequate shelf-life on exposure to moisture in cigarette packs. Oxidation catalysts would, in any case, produce an untoward rise in filter temperature owing to the heat evolution in the exothermic oxidation of CO to CO₂.

- Smoke dilution through permeable filter tips :

There are certain advantages inherent in this approach.

- (i) The reduction in nicotine is less than the reduction in tar, so that there is an increase in nicotine:tar ratio.
- (ii) The reduction in carbon monoxide is greater than the reduction in tar (this arises because the reduction in CO by dilution is augmented by enhanced diffusional loss of CO through the cigarette paper and more complete oxidation of the gases in the burning coal).
- (iii) Both tar and vapour phases are reduced so that tar:vapour phase balance in the smoke is maintained.
- (iv) Smoke dilution diminishes only slightly as the tobacco rod is consumed so that balance between early and later puffs is not seriously impaired.

- Smoke dilution through permeable filter tipping and reduced tobacco weight :

Whilst in the model cigarette only the use of a reduced tobacco filler weight has been considered, there are other methods which can be used to ensure that less tobacco is available for combustion during the puffs. As already mentioned earlier in this document, this includes the use of highly porous cigarette papers or papers having appropriate burn accelerators.

2501015113